Seed movement of bare alkali-saline patches and their potential role in the ecological restoration in Songnen grassland, China

WU Ling [1], HE Nian-peng [1], ZHOU Dao-wei [2*]

[1] *Laboratory of Quantitative Vegetation Ecology, Institute of Botany, Chinese Academy of Science, Beijing 100093, P. R. China*

[2] *Key Laboratory for Vegetation Ecology, Northeast Normal University, Changchun 130024, China*

Abstract: The dynamics of soil seed banks and seed movement was investigated in three bare alkali-saline patches in Songnen grassland, Northeast China, for exploring their potential role in the vegetation restoration of bare alkali-saline patches. The results showed that the seed banks and the seed movement in these patches were very similar to each other, and to some extent the seed movement was related to patch-side vegetation there. Seed movement across the soil surface of these bare alkali-saline patches was abundant and dominated by the seeds of pioneer species, such as *Chloris virgata* and *Suaeda corniculata*, which accounted for over 96% of these trapped seeds. In the contrast, soil seed banks of bare patches were extremely small, in different seasons, especially in May and June, even no any seed have been found, mainly due to lowest retaining capacity of surface soil to those abundant seed movement. Both soil seed banks and seed movement showed seasonal variation, and usually reached the maximum in October. Soil seed banks of bare alkali-saline patches, which were extremely small and difficult to recruit naturally, may inhibit speed of vegetation restoration. It is suggested that seed movement would be the potential seed source and play a potentially important role in the process of vegetation restoration of bare alkali-saline patches by enhancing the soil retaining capacity to seed movement.

Keywords: Soil seed banks; Seed movement; Bare alkali-saline patches; Restoration ecology

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Introduction

Songnen grassland (semi-arid steppe), which is dominated by *Leymus chinensis*, provides the principal grazing and mowing pastures in northeast China. However, because of extensive human exploitation since the 1980s, more and more grassland area has been alkali-Saline. Now, the alkali-saline grassland has already reached an area of 2.43×10^6 hm^2, with more and more bare alkali-saline patches that were degenerated into from typical steppe (Zhang *et al.* 2001). In some regions, the area of bare alkali-saline patches is over 50% of the total (Zhen *et al.* 1999). Although the significance of re-vegetation and improvement of alkali-saline grassland has been gradually understood by the local government and local people since 1990's, effect of re-vegetation is not satisfactory and bare alkali-saline patches has not been effectively controlled based on satellite photographs (Zhang *et al.* 2001). Up to now, how to effectively restore these bare patches is still a crucial and emergent task for ecologists.

Soil seed banks play prominent ecological and evolutionary roles, in linking the past, present and future of community structure and dynamics in a given habitat. Many studies have been carried out on soil seed banks (Kalamees *et al.* 1998; Onaindia *et al.* 2000; Nathan *et al.* 2000; Augusto *et al.* 2001; Gutiérrez *et al.* 2003; Jalili *et al.* 2003), seed dispersal (Cabin *et al.* 2000; Inglis 2000; Mayor *et al.* 2003; Bai *et al.* 2004), and lateral movement of seeds across soil surface (Aguiar *et al.* 1997; Rand 2000; Decaëns *et al.* 2003; Nathan *et al.* 2004) in different vegetation types. This is particularly true in some extremely deteriorated habitats, such as desert, salt playa, where soil seed bank are particularly important for re-vegetation though they are trivial in magnitude (Guo *et al.* 1998; Gul *et al.* 2001). To these particular habitats, lack of seeds in soil is prevalent, and how to recruit their soil seed banks is a constraint to their ecological restoration.

Soil seed banks in these bare alkali-saline patches are extremely small, because intrinsic seeds in soil have been lost with the loss of surface soil. We assumed that lack of seeds in soil, especially those of pioneer species, would be a controlling factor in inhibiting the restoring speed of bare alkali-saline patches towards a mature grassland community. Seed sources for natural re-vegetation of bare alkali-saline patches are mainly recruited from patch-side vegetation, and directly from seed movement across these bare patches. Seed movement across the soil surface of these alkali-saline patches is an available seed source for re-vegetation and increasing soil seed banks of alkali-saline patches. However, our present understanding to seed movement is still poor. Therefore, explicit knowledge of seed movement across the soil surface of alkali-saline patches would be very important in the establishment of restoration policy or strategies. In this study, seed movement is also defined here as the flux of seeds arriving at unit area per unit time in these bare alkali-saline patches (Aguiar *et al.* 2000).

The present paper has three objectives: (1) To investigate the dynamics and magnitudes of soil seed banks, and seed movement in these bare alkali-saline patches; (2) To compare the species composition of seed movement with that of patch-side vegetation; (3) To explore the potential role of seed movement for the ecological restoration of bare alkali-saline patches.

Materials and methods

Study area

The study was conducted on degraded grassland near the

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Biography: WU Ling (1977-), female, Ph.D. in Laboratory of Quantitative Vegetation Ecology, Institute of Botany, Chinese Academy of Science, Beijing, 100093, P. R. China.

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*Corresponding Author.: E-mail address: wl_ling@hotmail.com or Zhoudw@neun.edu.cn

Grassland Ecology Field Station of Northeast Normal University, on the Changling Horse Breeding Farm, Jilin Province, China in 2001 (44°35′N, 123°31′E). The grassland is situated at an average elevation of about 141 m and is surrounded by sand dune relatively altitude of which is about 20 m. Most of grassland area is with saline meadow soil. The typical grassland (semi-arid steppe) here has been dominated by *L. chinensis*, a perennial grass that has good palatability and high forage value, and provides the principal grazing and mowing pastures in the area.

The area was influenced by the continental monsoon climate, with large seasonal temperature variations (from −34°C to +37°C). The main characteristics of the climate are: a dry, windy spring; a warm, rainy summer; a cool autumn with early frost; and a long cold winter with little snow. The annual mean precipitation is about 457.5 mm, and the annual mean temperature is 4.9 °C. Monthly average precipitation and temperature in the study area are given in Fig. 1. Main precipitation period is from June to August in this area.

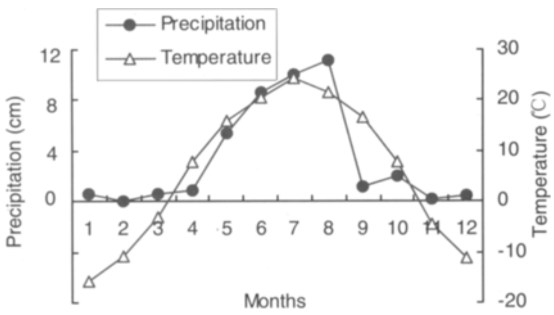

Fig. 1 Monthly field precipitation (cm) and temperature (°C)

Songnen grassland has been deteriorated or alkalized-salinized since 1980's. There now emerges a mass of bare alkali-saline patches due to a regressive succession caused by irrational exploitation in the past two decades (Fig. 2), in which few plant species vegetated at the growth period. The intrinsic soil of these bare alkali-saline patches has been severely destructed and loss. The soil pH can be as high as 10 in spring and summer. The re-vegetation process of these bare grounds is very slow under natural condition.

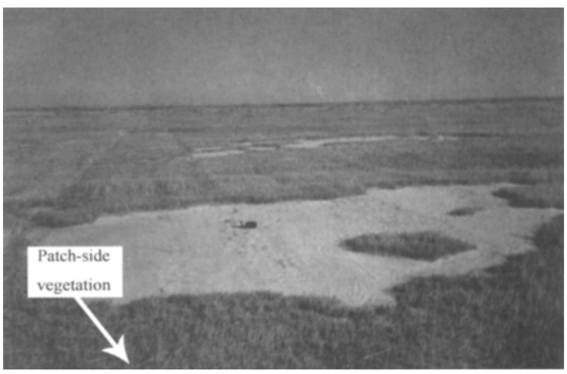

Fig. 2 Bare alkali-saline patches in fall in Songnen grassland

Experimental plots

Three experimental plots were selected on a mowing pasture of approximate 4000 hm^2 in area, which had been fenced for 6 years prior to the commencement of the experiment. The first bare alkali-saline patch (B_1) was located in the light alkali-saline grassland where the area of bare alkali-saline ground occupied less than 15% of the total grassland area. The second bare alkali-saline patch (B_2) was located in medium alkali-saline grassland where the bare alkali-saline ground covered 15%–50% of the total grassland area. The third bare alkali-saline patch (B_3) was located in the severe alkali-saline grassland where the bare alkali-Saline ground covered more than 50% of the total grassland area (Zhen *et al.* 1999).

Sampling of soil seed banks and seed movement

In 2001, Sampling of soil seed banks in bare alkali-saline patches (B_1, B_2 and B_3) was monthly carried out from May to October. Six soil cores (10 cm diameter, 15 cm deep) were taken at 1–1.5 m interval every time in each patch. To study the lateral movement of seeds over the surface of bare alkali-saline patches, we set pitfall traps with their rim at the soil surface in April 2001. In each of bare alkali-saline patches, 30 pitfall traps in total were located. Each trap was 6 cm × 6 cm in area and 15 cm deep, and had small holes in the bottom for water drainage. Sampling was carried out at the same time with sampling of soil seed bank, and then replacing these traps.

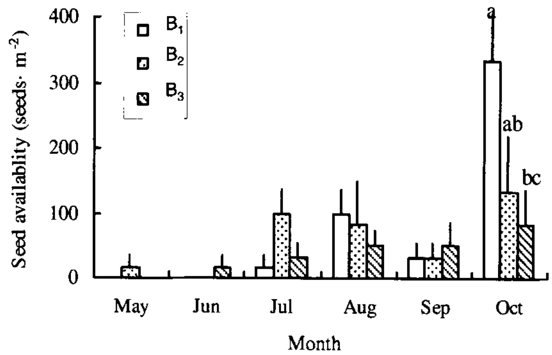

Fig. 3 Soil seed banks in bare alkali-saline patches at different date. Different letters represent significant differences for a given date.

B_1----the first bare alkali-saline patch; B_2----the second bare alkali-saline patch; B_3---- the third bare alkali-saline patch

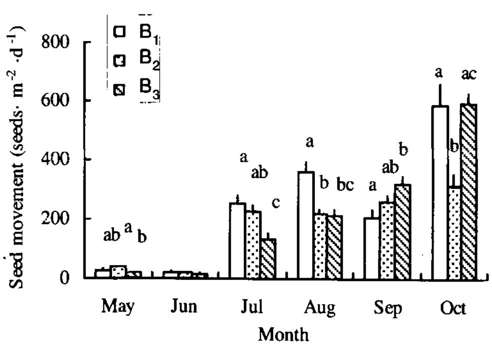

Fig. 4 Seed movement across the bare alkali-saline patches at different dates. Different letters represent significant differences for a given date.

B_1----the first bare alkali-saline patch; B_2----the second bare alkali-saline patch; B_3---the third bare alkali-saline patch

In the laboratory, each sample of soil seed bank and seed

movement was first washed through nested sieve of 0.2 mm diameter in order to remove sediments or other dissoluble material. Then, the seeds in each sample were identified under magnifying glass, and then comparing with the seed specimens gathered by Yang *et al.* (1995). Seeds detected in samples were classified into four groups:

L. chinensis, the dominant plant in typical grassland;

C. virgata, saline-tolerant pioneer plant;

S. corniculata, saline-tolerant pioneer plant;

Others, including such seeds that are rare or cannot be identified by this method.

Sampling of vegetation

In August 2001, the patch-side vegetation (Fig.2) was sampled to document their effect on seed movement and on soil seed bank of bare alkali-saline patches. Sampling was performed by using quadrat (1 m × 1 m) thrown 10 times at random. The material was oven-dry at 80 °C for 24 h and weighed. These data provided frequency value, and relative weight (percentages) of individual species or group (*L. chinensis*, *S. corniculata*, *C. virgata* and others).

Data analysis

Data on soil seed banks and seed movement in different micro-sites was square-root transformed for ANOVA (non transformed data was presented in Figs) (Performed with the SPSS statistical package v. 10.0). Morisita-Horn index of similarity (wolda 1983) was used to qualitatively compare species composition between seed movement and patch-side vegetation at each site (Ma 1994).

Results

Soil seed bank

No significant differences (P = 0.350) were observed in the number of soil seed banks between three bare alkali-saline patches; but, the number of soil seed banks was significantly different with months (P<0.001; Table 1). Significant difference was variable among sites, as indicated by the significant interaction between sites and month (P<0.001). There was a general tendency that soil seed banks in bare alkali-saline patches were extremely small at any time (Fig. 3), especially in May and June when seed in soil was extremely lacking, even no seeds were found. The maximum soil seed banks presented in October, and were only 333.3, 133.3 and 83.3 seeds per square meter in B_1, B_2 and B_3, respectively (Fig. 3). The soil seed banks of B_1 were similar with that of B_2, but higher than that of B_3 (P<0.05). The seeds of *C. virgata* were dominant in soil seed banks, while seeds of other plant species were scarce. It was noted that these soil seeds mainly distributed in the soil surface (found by field observation). So they are most likely to be carried away by wind or surface run off.

Seed movement

The number of seeds captured during trapping interval was significantly different among micro-sites (P = 0.004, Table 2). Seed movement number was maximum in B_3, less in B_1 and the least in B_2, in six months was totally 73065.3, 64766.2 and 77375.9 seeds·m^{-2} in B_1, B_2, and B_3, respectively. Similarly, significant effects were found with sampling dates (P<0.001). Seed movement was relatively low in May and June, but increased with time, and reached maximum in October (Fig. 4). In May, seed movement number in B_1, B_2, and B_3 were 28.8, 39.12 and 19.89 seeds·m^{-2}·d^{-1}, respectively; and in October, they were 588.2, 310.8 and 590.5 seeds·m^{-2}·d^{-1} respectively (Fig. 4). The reason is that the period after September is the maturation time of seeds of pioneer plants.

Table 1. Results of the ANOVA for soil seed banks

Source	df	MS	F	P
Site	2	32.733	1.06	0.350
Month	5	224.16	7.28	<0.001
Site×Month	10	318.75	10.55	<0.001
Error (Site×Month)	90	30.23		

Notes: Site represents the effect of the three types of bare ground where soil seed banks (B_1, B_2, and B_3) were sampled. Month represents the effects of 6 different periods.

Furthermore, it is noted that, in all sites, saline-tolerant pioneer plants (*C. virgata* and *S. corniculata*) were in importance in the seed movement (Fig. 5), though there existed great difference in floristic composition of their patch-side vegetation. The importance value of pioneer plants was 96.66%, 97.27% and 99.68% in B_1, B_2, and B_3, respectively. Correspondingly, *L. chinensis* accounted for only 0.74%, 0.22% and 0.02% of seed movement in above sites, respectively.

Table 2. Results of the ANOVA for seed movement

Source	df	MS	F	P
Site	2	70.63	5.53	0.004
Month	5	3225.24	252.39	<0.001
Site×Month	10	112.12	8.77	<0.001
Error (Site×Month)	407	12.78		

Notes: Site represents the effect of the three types of bare patches where seed movement was sampled (B_1, B_2, and B_3). Month represents the effects of the 6 different periods on which seed movement were sampled.

Relationship between patch-side vegetation and seed movement

Mean Morisita-Horn similarity coefficient of the species composition between seed movement and patch-side vegetation ((38.65±11.73)% S.E) was significantly (ANOVA, P = 0.038) higher than that between soil seed bank and patch-side vegetation ((7.77±3.76) % S.E). Mean similarity coefficient between seed movement and soil seed banks was highest in the three bare alkali-saline patches ((40.13±8.17) % S.E).

In order to clarify the relationship between patch-side vegetation and seed movement, the percentage of species between patch-side vegetation and seed movement classified was compared based on the above classifications (Fig. 5). *C. virgata* was dominant in seed movement, even accounting for over 97 % in B_3, although great difference existed in floristic composition of patch-side vegetation. There was a general tendency that pioneer species (*C. virgata* and *S. corniculata*) became more and more important in seed movement of bare alkali-saline patches, with the degradation of Songnen grassland. On the contrary, the importance of *L. chinensis* in seed movement was decreasing with the degradation of grassland. The importance of *L. chinensis* in seed movement was lower in the three bare alkali-saline patches, 0.74%, 0.22% and 0.02% in B_1, B_2, B_3, respectively, though its importance in patch-side vegetation was 74.72%, 38.81% and 16.73%, respectively. Accordingly, there existed positive correlation between the seed movement and patch-side vegetation to

some extent, probably because seed movement was mainly from patch-side vegetation to bare alkali-saline patches, and also because these pioneer plants (*C. virgata* and *S. corniculata*) usually produced abundant seeds that could easily be spread by wind.

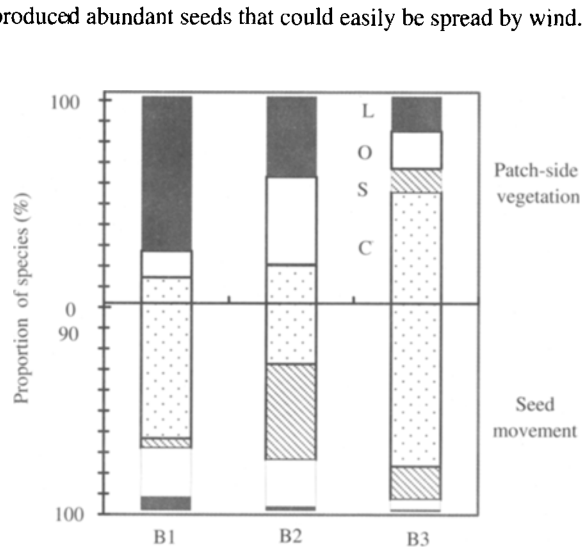

Fig. 5 Percentage of patch-side vegetation and seed movement for bare alkali-saline patches according to classifications
(L: L. chinensis; C: C. virgata; S: S. corniculata; O: other seeds)

Discussion

It is known that soil seed banks play very important roles in the processes of vegetation succession. Many studies have been carried out on soil seed banks in Songnen grassland (Yang *et al.* 1995; Zhen *et al.* 1999; He *et al.* 2004). Despite intensive attentions on the mechanism and the direction of vegetation succession for bare alkali-saline patches in Songnen plain (Zhen *et al.* 1999; Xin *et al.* 2000; Zhang *et al.* 2001), the studies on seed movement across bare alkali-saline patches and their significance for ecological restoration have not been reported.

The relationship between species composition of vegetation and soil seed bank is fairly well documented (Aguiar *et al.* 1997; Lópea-Mariño *et al.* 2000). Likewise, there also existed to some extent positive correlation between seed movement across bare alkali-saline patches and their patch-side vegetation, and seed movement had very high proportions of pioneer species.

Soil seed banks in the bare alkali-saline patches are extremely small, especially for May and June. They are far lower than that of typical steppe in Songnen plain which was reported by Yang and Zhu (1995). At the same time, experimental results showed that seed movement across bare alkali-saline patches was abundant and dominantly composed of seeds of pioneer species (*C. virgata* and *S. corniculata*). Totally, several factors may be involved in the extremely low soil seed banks in bare alkali-saline patches: (1) loss of intrinsic seed banks with soil loss; (2) rapid germination and high mortality of seeds in these bare grounds; (3) post-dispersal seed loss by wind and water (Hyatt *et al.* 2000); (4) too little soil seed bank input caused by their slippery surface and low retaining capacity to seed movement.

In another experiment, through the seeding experiment of *C. virgata* and *S. corniculata*, we studied their seeds germination characteristics and seedling growing dynamics in bare alkali-saline patches under natural conditions, and found their seeds both had high germinating capacity (74.3% and 76.1%, respectively), (He *et al.* 2004a). *S. corniculata* was able grow in bare alkali-saline patches under natural condition without any additional treatment, and its ultimate survival rate was 61.2% at the end of growing period. Survival rate of *C. virgata* was only 5.7% in the same natural condition; however, its survival rate can reach 43.1% with some simple auxiliary treatments. More importantly, *C. virgata* and *S.* corniculata both can reproduce successfully and provide necessary seeds for subsequent natural succession in these bare grounds. Therefore, lack of seeds, especially pioneer species should be the one of controlling factors, which inhibited the speed of restoration of these bare alkali-saline patches towards a grassland community. Considering the presence of the substantial seeds of pioneer species in seed movement and also considering the germinatation and growth habits of pioneer species (*C. virgata* and *S. corniculata*), it can be concluded that seed movement may play a potentially important role in re-establishment of bare alkali-saline patches.

For many typical ecosystems, successful seed germination and seedling establishment have been attributed to a wide variety of environmental factors (precipitation, temperature, etc.), their interactions, and their variation in time and space. In early stages of secondary succession, seed availability and environmental stress should be involved (Aguiar *et al.* 1997; Hyatt *et al.* 2000). In fact, lack of soil seed banks and high alkali-saline stress, rather than temperature and precipitation (Fig. 1), are main constraint for vegetation restoration of bare alkali-saline patches in Songnen grassland. Therefore, how to enhance the soil seed banks was very important for restoration of these bare grounds. In other experiments, our results supported the assumption that the increase of soil seed banks, by enhancing the soil retaining capacity to seed movement or increasing soil seed banks, significantly accelerated the vegetation restoration of bare alkali-saline patches (Wu *et al.* 2002; He *et al.* 2004 b). Of course, further researches are needed to clarify the mechanism and process of seed movement to vegetation restoration or succession in bare alkali-saline patches.

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